Robotic Weed Control

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In their 2008 comprehensive review of autonomous robotic weed control systems, Slaughter et al. (2008) reported that systems for plant detection and their classification (crop vs weed) presented the greatest technical challenge for development of a successful weeding robot. Methods for precision weed control also needed further development. Although thefew fully autonomous robotic weeding systems that had been developed at the time showed promise for reducing hand labor and/or pesticide requirements, none had been successfully commercialized. Since then, technology has advanced and several automated weeding machines are commercially available. This paper describes some of these devices and provides an update on the current state of robotic weeding.

Commercial robotic weeding machines utilize one of several means to kill weeds including mechanical, flame or herbicidal spray. Robotically controlled devices are used to eliminate weeds in the seed line between the crop plants (intra-row) while weeds between the seed lines (inter-row) are controlled with conventional cultivation techniques. All systems use a camera-based machine vision system to detect plants. Due to proprietary reasons, the specifics of how these machines' computer algorithms work is not known, but based on observation and a review of product literature; it is assumed they donot classify plants as being either crop or weed, but rather selectively identify crop plants. Classifying plants as either crop or weeds is difficult with system accuracies of around only 85%, even under ideal conditions. There are many ways to identify crop plants in digital images, but typically this is done by first analyzing a captured imaged and classifying each pixel in the image as being either a plant or a non-plant part using some type of green thresholding technique. Once the image has been "segmented", adjacent pixels are analyzed. Regions with high levels of contrast between plant and non-plant parts indicate potential leaf edge boundaries and contour lines are traced around the borders of these areas. These "objects" are then further analyzed based on size, location relative to each other, position relative to the seed row, shape and color. Objects that do not meet the user defined criteria as being characteristic of a crop plant are removed from the segmented image. Once crop plant objects have been located, commands are sent to a microcontroller which controls the intra-row weeding device. An example of the image processing technique described is depicted in figure 1. In this example, the machine vision system is used to identify plants for the purpose of selective

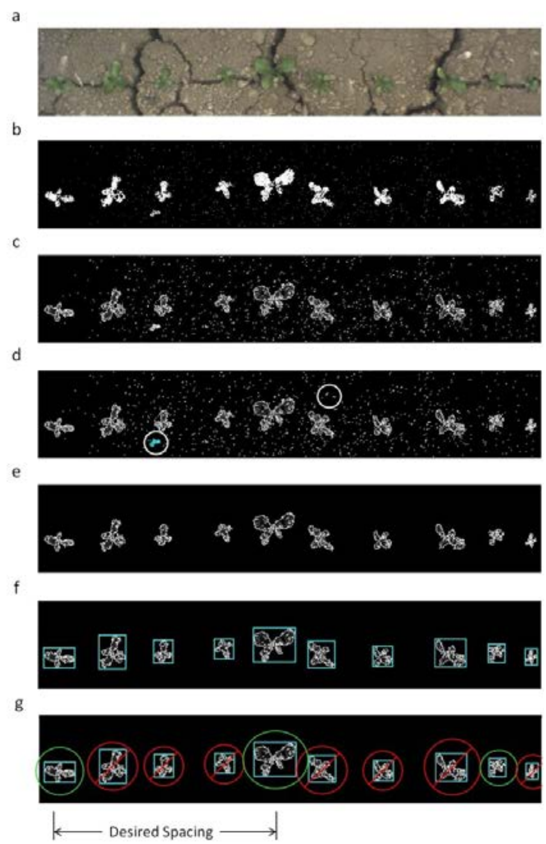

Fig. 1. Illustration of the image processing steps used by a robotic thinning machine: a) raw image captured, b) image segmented image based on color thresholding (green), c) contours traced around regions of high contrast, d) objects contained within contour boundaries are further analyzed for color, size and shape, e) objects that do not meet criteria for crop plant color, size and/or shape are filtered, f) bounding boxes placed around plant objects identified, g) plants to be "saved" or selectively thinned are chosen based on plant location and desired final plant spacing.

thinning. Plants to be "saved" are selected based on the desired final plant spacing.

The first commercially available robotic weeding machine was probably a device called the Robocrop. The technology was developed by Tillet and Hague Technology Ltd. (Silsoe, United Kingdom) and commercialized by Garford Farm Machinery Ltd. (Peterborough, England). The device utilizes a forward looking camera to detect crop plants and sets of rotating disc blades attached to an off center shaft to cultivate around crop plants and within the crop row. Fennimore et al. (2013) compared the device with hand weeding in direct seeded and transplanted Bok Choy, celery, lettuce and radicchio. They concluded that the machine provided acceptable performance in transplanted crops, but was not suitable for use in directed seeded crops. An explanation for this is that in addition to color, the machine's plant detection algorithm utilizes plant spacing and size as selection criteria. In direct seeded crops where crop plants are irregularly spaced and of similar size to weeds, the system has difficulty reliably differentiating between crop and weed plants.

The IC-Cultivator, manufactured by Machinefabriek Steketee BV (Harringvleit, Netherlands), has been in commercial production for only two years. The technology was developed in partnership with Wageningen University Research (Wageningen, Netherlands). The robotic weeding machine utilizes cameras, one for each crop rowto identify crop plants based on color, size and spacing. To ensure that images of consistent quality are obtained, the cameras are enclosed in a hood and artificial lighting is provided by LEDs. As the machine travels through the field, a pneumatic cylinder is actuated to open and close a set of cultivating knives around the crop plants. The machine was released in Europe in 2013 and several units will be available in North America in 2014 via Northern Equipment Solutions (Wasage Beach, Ontario, Canada). According to product literature, the unit is modular in design providing for working widths of ranging from roughly 5-20 feet. Hoeing capacity is 3-4 plants per second. With plant spacing at 11 inches, this translates to an operating speed of 1.9-2.5 mph. The price for a six row unit is $80,000 or about $13,000 per row. No information about the performance of the machine could be found.

F. Poulsen Engineering Aps. (Hvalsø, Denmark) manufactures a similarly styled mechanical hoeing robot. The unit utlizes cameras positioned over each crop row anddetects crop plants based plant color, size and spacing. Intra-row weeds are controlled by knife blades that are opened and closed around crop plants as the machine travels through the field. Although the cameras are not enclosed in a hood, artificial lighting is provided so that images of consistent quality can be obtained. Depending on soil and plant conditions, product literature states that the machine is capable of operating at speeds of up to 2.5 mph and available in modular 3-6 row units. Multiple modules can be mounted on a toolbar to provide wider working widths. The cost of the system is about $125,000 for a five row unit (about $25,000 per row) and there is no known U.S. distributor. No information about the performance of the system could be found.

F. Poulsen Engineering Aps. (Hvalsø, Denmark) also manufacturers an intra-row weeding robot that uses flame to kill weeds. The machine uses the Robovator vision system to identify crop plants. A series of plasma jets oriented towards the crop row are cycled on and off to kill weeds between crop plants. Multiple jets are used for each crop row so that a sufficient amount of heat is applied to kill the weeds. The company's website states that the patented system can be operated at speeds of 0.6-3.75 mph. Again, no information about the performance or cost of the system could be found.

Automated lettuce thinning machines can be thought of as intra-row weeding robots since they are used to remove undesired plants in the seed row. Since 2011, four automated thinners have been commercialized in the U.S. These include units from Ramsay Highlander Inc. (Gonzales, Calif.), Agmechtronix LLC, (Silver City, N.M.), Blue River Technologies Inc. (Mountain View, Calif.), and Vision Robotics Corp. (San Diego, Calif.). All systems use a machine vision system to locate lettuce plants for selective thinning and herbicidal spray solutions to kill unwanted plants. These machines are capable of thinning crops planted as close as 1.5 inches apart as speeds of 2-3 mph.

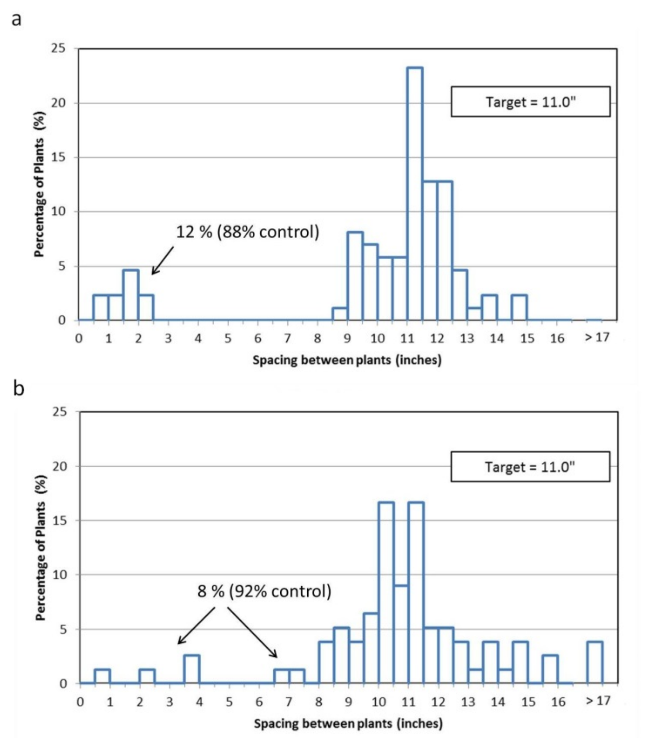

Fig. 2. Plant spacing distribution after thinning lettuce seedlings nominally spaced 2 inches apart with a) an automated thinner and b) by hand.

Prices for a tractor pulled four bed (2 wide beds) machines are roughly $150,000 while self-propelled, two bed (1 wide bed) units cost $250,000. The technologies utilized by these devices could easily be adapted for robotic weeding purposes since crop plants are identified by color, size and location. The technique shows promise. Siemens et al. (2012) evaluated a prototype automated lettuce thinner and found that the system was able to control 88% of the unwanted lettuce plants within 8 inches of the saved crop plant (Fig. 2). This was comparable to hand thinning where 92% of the unwanted lettuce seedlings were controlled. Better performance should be expected today since technolgy has advanced since the time of the study. To utilize automated thinning technologies as robotic weeding machines, theortically all that is needed to have the user be able to adjust thesize of the ”objectes” the system considers to be a crop plant. This can easily be accomplished programatically. The unit would also need to be equipped with banding nozzles to spray and control inter-row weeds. It is not known how well such a system would control intra-row weeds, especially those close to the crop plant and further research is needed. We have initiated studies to address this issue.

In summary, over the last several years, several technologies for robotic weeding have become commercially available. To date, there is little information about their performance or their viabilty for use in California production systems. Research is needed to address issue. Automated thinner technologies show good promise for use as robotic weeding machines, but further study is also needed. As technologies continue to advance, robotic weeding machines will become more precise, have expanded capabilities and be more affordable. It is reasonable to expect that these type of devices will play an will play an increased role in production agriculture in the future.

Links to some of the videos shown during presentation are provided below.

Robocrop (Garford Farm Machinery Ltd., Peterborough, England):
http://www.thtechnology.co.uk/Movies%20and%20thumbs/Robocrop%20in-crow%20weeder.wmv

IC-Cultivator (Machinefabriek Steketee BV, Harringvleit, Netherlands):
http://www.youtube.com/watch?feature=player_embedded&v=NrozkDh4VxQ

Robovator (F. Poulsen Engineering Aps., Hvalsø, Denmark):
http://www.youtube.com/watch?v=qeYyWiLfiYw

Thermal Hoeing Robot (F. Poulsen Engineering Aps., Hvalsø, Denmark):
http://www.visionweeding.com/Videos/flame-normal-speed.wmv

References

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Siemens, M.C., R. Herbon, R.R. Gayler, K.D. Nolte and D. Brooks. 2012. Automated machine for thinning lettuce - Evaluation and development. ASABE paper No. 12-1338169, pp. 14. St. Joseph, Mich: ASABE

Slaughter, D.C., Giles, D.K. and D. Downey. 2008. Autonomous robotic weed control systems: A review. *Computers and Electronics in Agriculture* 61: 63-78.

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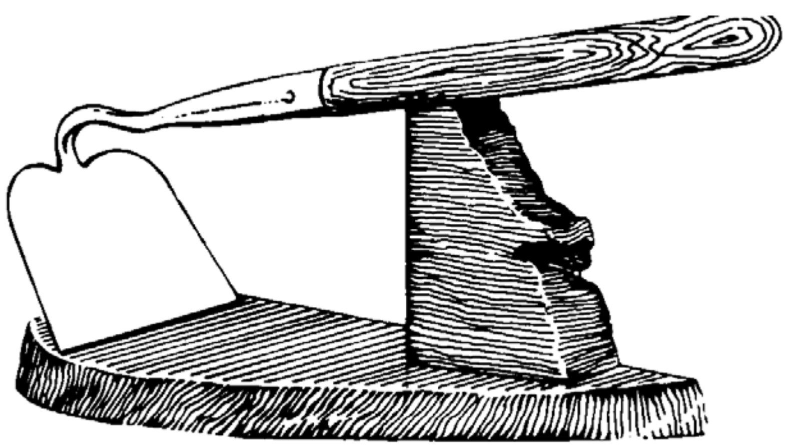

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